# HOW AN R. F. SIGNAL IS DEMODULATED, DETECTED, RECTIFIED, ETC.

LESSON ND-17

SPRAYBERRY ACADEMY of RADIO

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PUEBLO, COLORADO

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LESSON ND-17

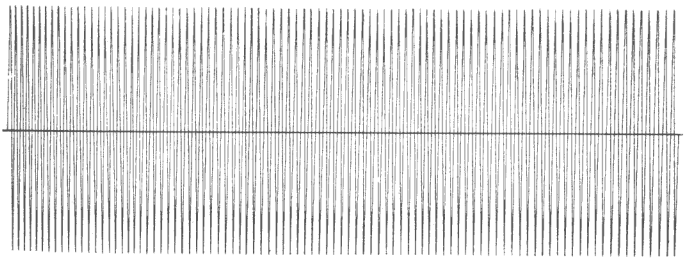
In your studies up to this point, you have covered most of the main sections of a radio receiver with the exception of oscillators (as used in the superheterodyne type receiver) and demodulation. Oscillators will be treated in the lesson on superheterodynes and this lesson will treat demodulation.

You have seen how the R.F. amplifier selects a very weak R.F. signal and builds it up in strength to where it is suitable to operate a *detector*. Then we explained how various types of A.F. amplifiers accepted the A.F. or low frequency signal from the detector and again the signal was built up in strength by amplification until it was strong enough to operate a speaker. The process of detection was purposely omitted in the sequence of lessons until you were taught the principles of A.F. amplification. One purpose of this was to emphasize the importance of the *detector as a vital connecting link* between the R.F. and A.F. amplifier. *It is the medium by which the signal is translated from energy in the form of high frequency to energy in the form of low frequency.*

It has already been explained in former lessons that the process of combining the *original A.F. signals* with *a high frequency* so as to make the latter act as a *carrier* for the A. F. signals is called *modulation.* These two frequencies combined as described are known as the radiated modulated carrier. They are thus radiated in every direction outward from the transmitter and so act on thousands of receiver antennas or pick-up devices both near and at great distances from the transmitter. The R.F. amplifiers of the receivers thus feed the signal energy to their respective detectors.

Since the mixing or combining of the original A.F. signals with the high frequency carrier is called *modulation,* the separation of these at the receiver is logically called *demodulation.* This is the proper technical term but, as happens in so many other cases of similar nature, a more popular term has come into use to supplant that of demodulation. The action taking place in the circuit is called *detection,* and the unit or stage which accomplishes the detection is called a *detector.* Because detection is similar to rectification, the detector may also be called a high frequency rectifier. Thus you will encounter the terms demodulation, detection and rectification. As applied to detectors of high frequency energy, these terms all mean the same thing. Likewise, demodulator, detector and rectifier all refer to the same thing. To be consistent with the rest of the radio industry we will use the words detector and detection.

In studying the various detection methods described in this les-



HIGH FREQUENCY CARRIER WAVE

FIG. 1

son, one point you should continue to keep in mind is that the *only function of the carrier wave is to act as a train to haul the audible frequencies from the transmitter to the receiver.* Once the signal arrives at the receiver the carrier has done its job, and as soon as the necessary strength is attained by R.F. amplification, the high frequency carrier energy must be removed or eliminated from the audible frequencies before the A.F. can act on a speaker so as to provide audible sound waves. So the carrier is a necessary unit in the chain of transmitter-receiver events until a way is discovered to efficiently radiate A.F. signals directly over great distances.

Before detection can be understood, it is first necessary for the student to have a good, clear picture in his mind of the nature of a modulated high frequency wave form. He should understand that it can be resolved into three fundamental unit parts. These are (1) the high frequency carrier wave, (2) the low frequency audible frequencies and (3) the combined carrier and audible frequencies.

In order that a specific case may be considered, a carrier frequency in the broadcast band may be used as an example to show the various types of wave forms involved and what takes place during the process of detection. The broadcast band, you will remember, includes that band of frequencies between 540 and 1600 KC. Stations on this band of frequencies are allotted a carrier frequency assignment by the Federal Communications Commission (known as the FCC). These carrier frequency allotments are spaced 10 KC apart in the band in which each one is permitted to broadcast signals up to 5000 cycles each side of its assigned carrier frequency. A radio station assigned this carrier frequency may transmit over a maximum range of from 1000 KC − 5 KC or down to 995 KC and up to 1005 KC or 1000 KC + 5 KC. This is a maximum range of 10 KC − 5 KC each side of the carrier frequency. The latter are known as *side band frequencies* and within them is contained the *maximum peaks* of both the carrier and modulating frequencies. This, in brief, is a description of our 1000 KC modulated carrier frequency example.

You are naturally interested in a physical description of the high carrier frequency. One of the best ways to represent it is as in Fig. 1. Here the carrier frequency alone is represented by a series of cycles

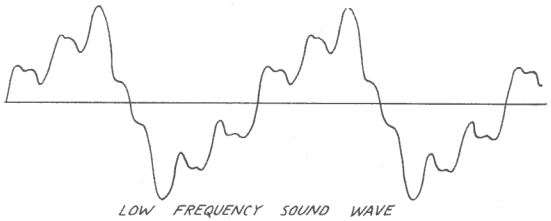


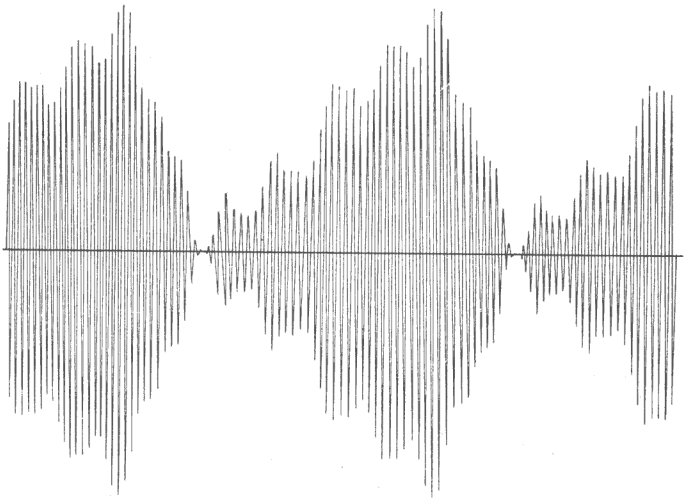
FIG.2

of A.C. closely spaced together. The fact that they occur so closely together indicates that a high frequency is involved. This may be considered to be the output wave form of any suitable A.C. generator. As shown in Fig. 1, only the pure symmetrical high frequency wave form is represented—be sure to keep that fact in mind as you continue the study of this lesson.

Next consider the lower A.F. frequencies. These, as a rule, represent not pure symmetrical cycles but rather tone or sound wave forms. These cannot be represented as pure symmetrical cycles for the very fundamental reason that they are made up of varying frequencies consisting of fundamentals and harmonics, as you learned from the lesson on push-pull amplification. It is because of this that the A.F. or modulating frequencies must be represented by complex wave forms. As you have learned, the combination of fundamental and harmonic frequencies representing actual sounds can be resolved into an equivalent wave form. Such a resultant wave form is shown in Fig. 2. It can be taken to represent the general wave forms of actual sound waves regardless of their origin. Therefore, you should always think of the modulating frequencies as represented by *complex wave forms* such as those shown in Fig. 2.

Thus you have the picture of a separate high frequency carrier wave and a separate A.F. low frequency complex sound wave. The next step is to get them combined into one single wave form. In the transmitter this function is accomplished by feeding the high frequency carrier energy and the A.F. modulating energy into a suitable tube which combines the two frequencies (since this lesson is on receivers, the complete details of the transmitter will not be described at this time) to form a *new complex wave form* known as the modulated carrier wave form. This is the final wave form as it is radiated by the transmitter.

You learned from your study of the lesson on push-pull amplification that fundamental and harmonic frequencies *would, if combined in phase, result in an addition of the wave forms to give one total effective wave form.* Exactly the same principle is involved when a carrier frequency and modulating frequencies are combined. The resulting wave form is neither a copy of the carrier nor the modulating wave form. *Instead, the new wave form is an average of the two wave forms.* For our example, if the carrier wave form of Fig. 1 is suitably combined with the modulating



MODULATED HIGH FREQUENCY WAVE

FIG. 3

wave form of Fig. 2, the average or addition of the two will appear as in Fig. 3. This resulting wave form is obtained by adding every peak of the modulating frequency to every peak of the carrier wave. It is in this way that intelligence is made to ride on a high carrier frequency whether the intelligence be in the form of speech, music, noise, picture tones, dots and dashes, etc.

The process of modulating a carrier wave with modulating frequencies is a special study within itself which you may well defer until a later date so as not to interrupt the present series of lessons on receivers. Thus, you should now concentrate your efforts on the study of detection. The principle thing you need to remember about the modulated wave form is its general shape and the fact that it is a complex wave form which the detector stage in a receiver must demodulate.

The detector must do two important things. These are (1) separate the high frequency carrier from the modulating frequencies and (2) once the separation is accomplished, eliminate the carrier by filtering and then feed the remaining A.F. frequencies to a suitable A.F. amplifier, the characteristics of which you have already studied.

To again refresh your memory as to how an ordinary receiver functions, a block diagram is shown in Fig. 4. This is used to illustrate the progress of a radio signal through a radio receiver. Arrowheads are used to denote the direction in which the signal progresses through the receiver. You will note that the detector stage is located between the RF and AF amplifiers. Therefore, when this lesson is completed you will have completed the fundamentals of your study *on radio receiver sections* except for speakers. Types of complete receivers such as the TRF and superheterodyne will, of course, be treated in other lessons.

## OPERATION OF DETECTORS

The signal which is received and amplified by the *RF* or high frequency amplifier is not suitable for conversion into sound energy without making certain alterations or modifications in it. In studying the nature of the modulated high frequency carrier wave you will find that it represents nothing more than a variation of the average intensity of a rapidly reversing current.

This may be amplified to any extent desired, but it cannot be converted into sound. If this modulated carrier were converted into sound or air waves, the frequencies would be so high that they could not be heard by the human ear. Then, in addition, as you will learn later, a speaker diaphragm cannot move or vibrate at a sufficient speed for such high frequency—such variation in amplitude would be of no value. To be useful, the modulated carrier must be *accumulated* and made to act in *one direction* (be rectified). Then, as the carrier varies in intensity, the accumulated energy will be more or less effective, depending upon the carrier variations.

Signal detection is a method of discarding the carrier. This may be accomplished by rectifying the complex carrier wave and filtering it so that it can be used as audio frequency energy. This suggests that the study of detection may be divided into two parts, namely, *rectification and filtering.*

Knowing that all waves are combinations of sine waves, all you need to study is the reproduction of one sine wave, and you will have the whole story. The voltage of Fig. 3 is simply an amplified voltage equivalent of the radio wave as it comes from the transmitter. Consider it to be a carrier wave of 1000 KC modulated by a varying audio frequency.

There are many ways to rectify and filter a carrier in order that the original signal modulation may be obtained. You will study the important methods in detail in this lesson. The exact method employed depends on overall design requirements and the particular development time at which a given receiver is placed on the market. The radio man must be familiar with all general methods because he will find them in use in his work.

The modulated carrier voltage is available across the final tuned circuit of the R.F. amplifier. The R.F. amplifier is, therefore, considered the source of the modulated R.F. voltage although, if the detector

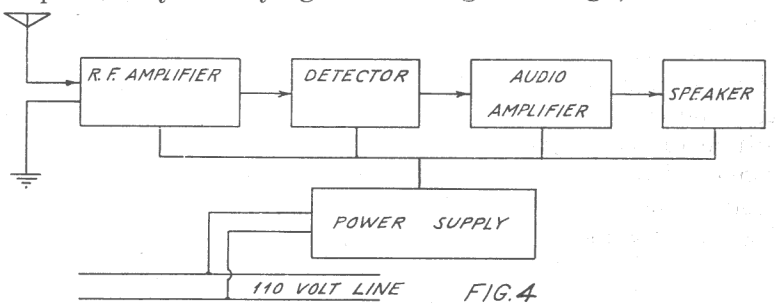


FIG. 4

were sufficiently *sensitive,* it could be supplied directly from a receiving antenna but at greatly reduced signal voltage. These two possible sources (antenna and R.F. amplifiers) for the *modulated carrier wave* can be assumed to apply to all the detector circuits discussed in this lesson.

## DETECTOR TERMS

When the *demodulated* or rectified output of *any detector* is proportional to the *square* (the input voltage value multiplied by itself) of the applied signal, it is said to be a *square law detector.*

*Linear* detectors give an A.F. output which is proportional to the amplitude of the modulation of the applied signal—directly proportional to the input.

*Grid leak or grid rectification* detectors are those which use a grid resistor and condenser. In these circuits the grid and cathode (or filament) act as a diode rectifier with the rectified voltage appearing across the grid and cathode; this voltage acts as a varying bias and controls the cathode to plate current as will be explained. Thus, such detectors are the equivalent of a diode detector and one low gain stage of audio frequency amplification.

*Plate detectors* are also sometimes termed *bias detectors* or *power detectors.* In this type the tubes are biased to the plate current cut off point. Only half of a cycle will affect the plate current so that the average output is approximately the same as the average amplitude of the signal. This will introduce *harmonics* in the output which will cause very evident *distortion* when handling strong signals—more about this later.

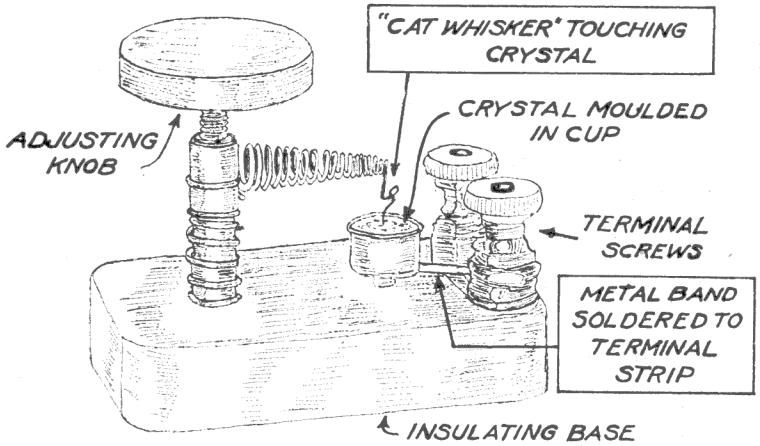
*Diode detectors* are those using two element vacuum tubes. These are *half wave rectifiers* and give good reproduction with strong input signals. They are relatively sensitive (performing as square law detectors) with weak signals.

*Crystal detectors* are those detectors making use of the inherent *rectifying* properties of certain minerals or crystaline substances.

## CRYSTAL DETECTORS

*Rectification,* in the early days of radio, was accomplished in various ways. The most practical of the many devices used by the early experimenters enjoyed a return to popularity during World War II and is used in many modern VHF (very high frequency) and UHF (ultra high frequency) apparatus. It is used in the remarkable *Radar* systems.

Early radio scientists discovered that many crystaline substances have, under certain conditions, an inherent natural ability to rectify small voltages or currents. These substances included *Galena, Pyrities, Carbon and Silicon.* Small pieces of these crystals were usually placed in a small metal cup or holder—sometimes they were mounted by inserting them in a soft metal with a low melting point such as Wood's metal—leaving one surface of the crystal exposed as shown in Fig. 5. Note also in the figure that the wiring symbols used in diagrams to denote *crystal rectification* are shown. A very small diameter sharpened wire (sometimes called the cat-whisker) is arranged to touch the crystal face lightly and acts as the sec-




AN EARLY CRYSTAL DETECTOR

FIG. 5

ond terminal of the rectifier (indicated by the arrow in the symbol), the crystal mounting being the first terminal. The crystal surface must be absolutely clean and fresh (even the oil from the skin of clean fingers will stop operation) and, as all spots on the crystal surface are not active, a sensitive spot must be found. Vibration or shock, and sometimes even a breath of air, is sufficient to dislodge the cat-whisker. In the old days, an operator virtually had to *hold his breath* while using these devices.

Later developments, however, included *fixed* crystal detectors which eliminated the trouble of losing, and finding again, a good *spot* on the crystal surface. One of these is illustrated in Fig. 6 and is representative of those available and used in today's modern equipment. As long as these *crystal rectifiers* are not overloaded they may be suspended in the wiring much the same as a small tubular condenser, and then need no further attention. The most popular present day crystal rectifiers use refined or electrolytic silicon with a tungsten probe (for the cat whisker).

As has been explained in other lessons, a rectifier is an electrical device which will allow current to flow freely in one direction but which offers resistance to the flow in the opposite direction. The ratio of the modern crystal detector's *forward* to *backward* resistance is as much as 1 to 4; in other words, the *backward* resistance is 4 times the *forward* resistance. This ratio compares favorably with many modern *diode* detectors about which you will learn later in this lesson.

Probably the simplest circuit using a crystal detector and headphones (for sound reproduction) is shown in Fig. 7. It is possible to hear strong local signals with this arrangement; however, there is no tuned circuit and because of this more than one transmitter may be heard at the same time. It

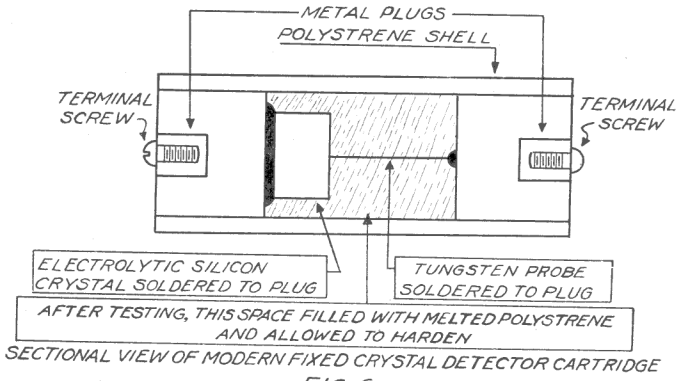

METAL PLUGS
POLYSTRENE SHELL
TERMINAL SCREW
TERMINAL SCREW
ELECTROLYTIC SILICON CRYSTAL SOLDERED TO PLUG
TUNGSTEN PROBE SOLDERED TO PLUG
AFTER TESTING, THIS SPACE FILLED WITH MELTED POLYSTRENE AND ALLOWED TO HARDEN
SECTIONAL VIEW OF MODERN FIXED CRYSTAL DETECTOR CARTRIDGE

FIG. 6

will be noted that the crystal detector and phones in Fig. 7 are in series with the source (in this case, the antenna). Since the source (antenna and ground or the output of a RF amplifier) supplies the *modulated carrier wave*—and because the crystal detector allows only that half of the voltage flowing in *one direction* to pass through the phones—the result is *varying* pulsations of *direct current* (at an audio rate) flowing through the phones. Because these varying pulsations *vary in voltage* as the modulation varies the amplitude of the *carrier wave*, the net result is a changing amount of A. F. energy to operate the phones as a sound-producing unit. At the low frequencies, electrical energy introduced in the headphone winding varies the pull against the diaphram, the resulting pulsations create sound waves as the diaphram snaps to and fro thus producing sound waves equaling those originally picked up by the microphone at the transmitter. Your next lesson will give more information on headphones and speakers.

Figure 8 shows another wave form representative of the modulated carrier wave. Note it is similar to the one in Fig. 1 except Fig. 8 represents a constant tone of 500 cycles. Figure 9 shows half of the *rectified carrier wave* as the result of crystal rectification, and this, in turn, is fed to the headphones.

Thus, the average *varying direct current* indicated by the heavy line in Fig. 10 represents the energy which acts on the diaphram in the headphones.

Since the mechanical diaphram of the headphones cannot move as rapidly as the number of voltage peaks per second of the *carrier frequency,* the diaphram will move only *as the average value of these peaks varies with the modulation.* Thus, some *filtering* is accomplish-

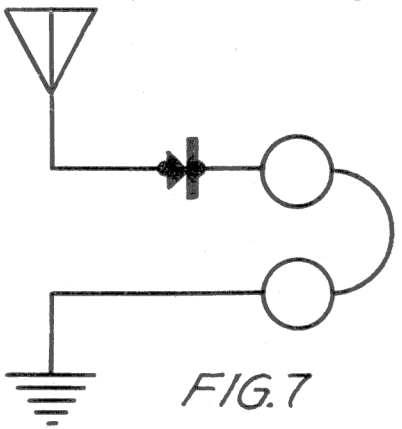


FIG. 7

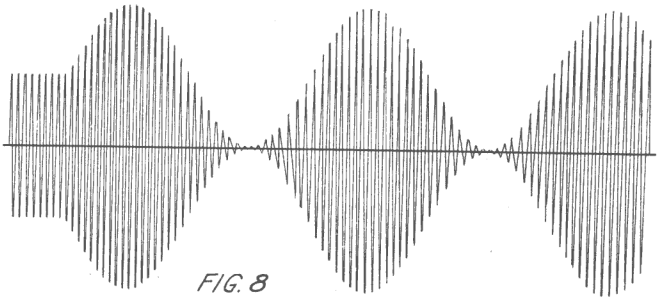


FIG. 8

ed by the physical characteristics of the headphones such as the *inductance* of the windings and the *inertia* of the diaphram.

In the improved circuit shown in Fig. 11, *filter* action is obtained by means of the small condenser $C_1$. The capacity value (reactance) of this condenser is so chosen that it will not *short circuit or* prevent a great amount of the low frequencies (AF) from entering the phones, and yet its reactance is small enough to *by pass* high frequencies (RF) around or past the headphones. This condenser's charge and discharge time will aid in *filtering* the R. F. since it will only discharge through the phones in between cycles of the carrier frequency. It receives its charge from the voltage peaks supplied to it by the crystal rectifier — thus helping to maintain the average pull on the diaphram. Since it receives its charge from the *rectifier*, it will help in smoothing out the average DC value of the voltage peaks furnished to the headphones as in Fig. 12. A condenser too large or too small at this point in the circuit would alter the *average* voltage through the headphones and result in *distortion*. It should be noted here that the filter action in most detector circuits described later in this lesson are founded on the same principles as outlined in the crystal detector circuit of Fig. 11.

With the advent of further developments in receiver construction, other more versatile and sensitive detectors came into existence. It would be well to remember, however, that the crystal detector used in the earliest wireless experiments is also employed today in many ultra modern electronic devices. Many alarm, signal, beacon and aircraft communication systems put the crystal detector to use, and it would be well for the student to be completely aware of the possibilities of one of radio's earliest and most useful detectors.

While crystal detectors function as *square law* demodulators on

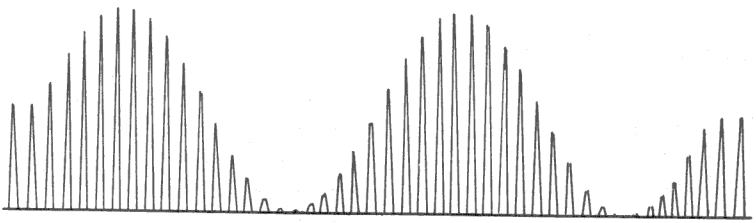


FIG. 9

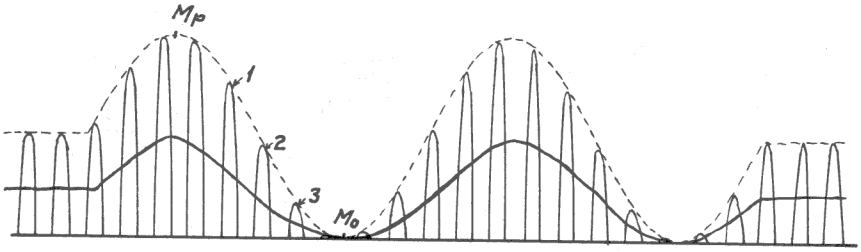



FIG. 10

weak signals, they may become ineffective with the application of a strong carrier. Their sensitivity factor compared to other rectifiers, and the difficulty in adapting them to *selective* circuits has lead to the development of other methods of detection. The inability of some crystals to withstand mechanical shock and vibration also renders them unsuitable for certain applications. On of their principle advantages is very low *internal capacity* which permits their use in *very high frequency* circuits.

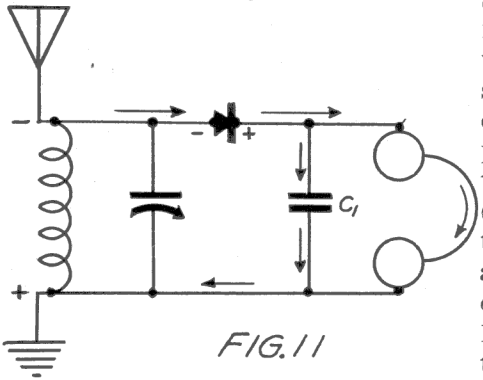



FIG. 11

## DIODE DETECTORS

One of the earliest detector developments was the use of a simple *diode* tube as the *rectifier* for detection of radio signals, as explained in an earlier lesson. The early vacuum tube detectors were crude. However, they were workable creations similar in construction to any *half wave* rectifier tube of today.

At this point it would be well to refer to your lessons on tubes. Note carefully the Edison effect. It is the *Edison* effect which is used in *diode detectors* or *rectifiers*. The fact that a *diode* t u b e will allow current to flow in *one direction only* is the *important* point to remember about them.

In the *crystal detector* discussion of this lesson, it was pointed out that the resistance offered to a voltage in one direction through the crystal was four times the resistance offered to a current in the reverse direction. The diode vacuum tube, however, will cut off or stop completely the voltage in one direction and offer very low comparative resistance to voltage in the desired direction. Thus, if a diode is substituted for the crystal in Fig. 11 and a voltage supply added to heat the filament or *cathode* of the diode—as shown in Fig. 13—a much more *sensitive* detector than the crystal will be obtained.

Note carefully that the circuit functions the same as the crystal circuit *except* that the diode is acting as a one way *valve* in place of the crystal. The simple addition of an input coupling coil and an output coupling coil would permit the use of this diode as the *detector* circuit coupling a RF amplifier section to the AF amplifier section of

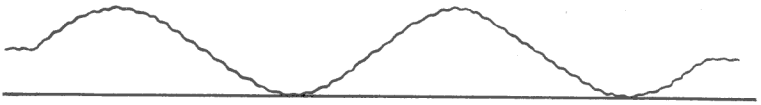


FIG. 12

a receiver as shown in the block diagram of Fig. 4. Isolating this particular *detector* circuit from the *receiver* wiring diagram of Fig. 14 will give the *detector circuit* shown in Fig. 15. *Note* the input coupling coil L, the output coupling or load resistor $R_L$, the tuning condenser C and the *diode* D.

Figure 8 will give an idea of the

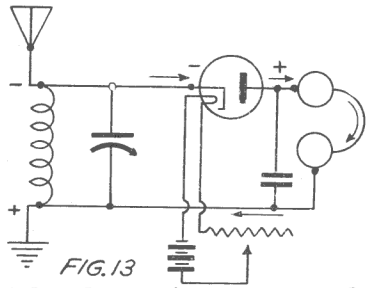


FIG. 13

*modulated carrier wave voltage* supplied from the transmitter. Since one-half of the voltage will flow as a result of rectification, the direction of current flow will be as indicated by the arrows in Fig. 15. Because of the uni-directional diode, only that portion of the original modulated wave form shown in Fig. 9 will be available across the output resistor $R_L$. This, then, in brief, is the simple explanation of the action in a *diode detector circuit.* The same principle is involved as was explained for half wave rectifiers for 60 cycle power supplies as described in your S. A. R. lessons on tubes. The only difference is that for power supplies, low frequencies are involved whereas in detector circuits, relatively high frequencies are involved.

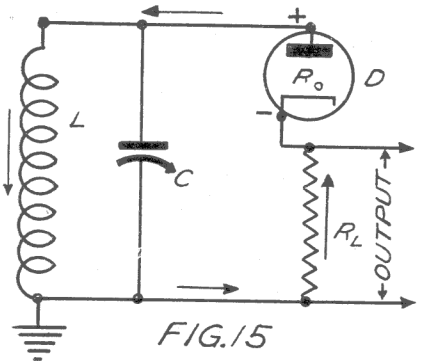



FIG. 15

You should remember that a *diode* tube provides *only demodulation* or detection and that *no amplification is obtained;* in fact, some loss occurs due to the IR losses in the tube and circuit. You should also understand that a diode detector requires no DC plate

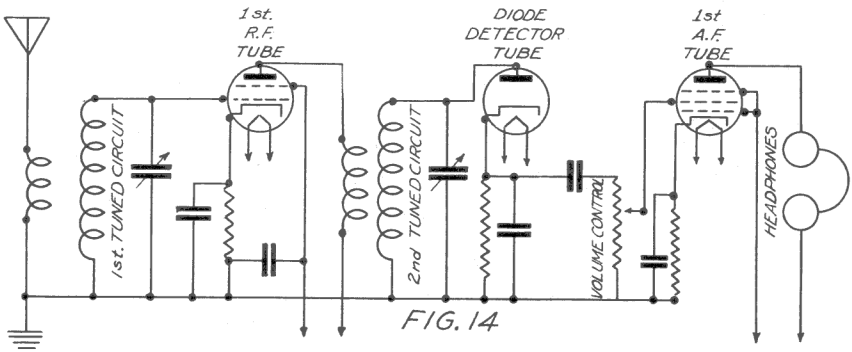



FIG. 14

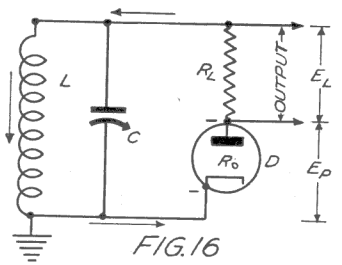


FIG. 16

voltage like the other tubes in the receiver. *The signal voltage as supplied by the RF amplifier is the only plate voltage needed to operate the diode detector tube.*

To aid you in obtaining a clear understanding of the electronic action in diode circuits, four possible diode circuits are shown in Figs. 15, 16, 17 and 18. In order to explain the action thoroughly, two assumptions must be made—first, that a modulated carrier voltage is induced in coil L; this voltage may come from an antenna coil, coupled inductively or from the plate of a RF amplifier, and, second, that this voltage must be *halted* as though you were able to visualize its flow as represented by the arrows. The next portion of a cycle of the induced voltage would, as you know, be in the opposite direction from that indicated by the arrows, and you need not consider this reverse flow because current can only pass through the diode when the induced voltage is such that electrons from the cathode will flow towards the positive plate. Note that the arrows, in all four diagrams, illustrate the flow of electrons *through the tube in the same direction.* If you were to *halt* this induced voltage when it was in the reversed direction from that illustrated, the plate of the diode would be at a *negative potenial* and *no electrons* would flow

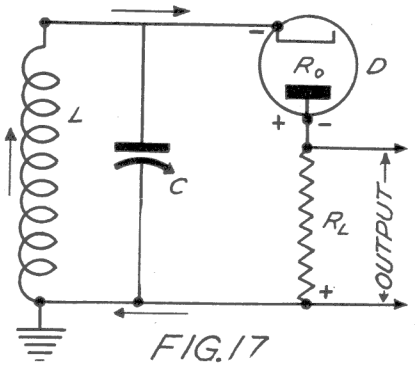


FIG. 17

from the cathode. This is why the flow is illustrated, as it is, by arrows.

In Fig. 15, L and C would be adjusted to resonance with the frequency of the induced voltage. (This will hold for all four illustrations.) As may be seen, this voltage developed across LC will be applied across $R_L$ and $R_O$ (representing *resistance of load and resistance of diode*). The diode will allow current to flow *only* when the plate is positive in relation to the cathode as illustrated *and not in the reverse direction.* Because of this current flow through the diode and load, a voltage will appear across these two resistances $R_L$ and $R_O$. As these two resistances are in series, any voltage across them will be divided according to their proportional resistances (refer to resistors in series in a previous les-

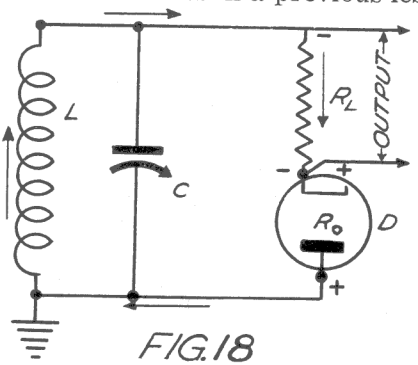


FIG. 18

son). If the diode resistance is equal to the load resistance, half of the applied voltage would appear across each. For example, if the tuned circuit LC produced an 11 volt potential across $R_O$ and $R_L$ and if $R_O = 50{,}000$ ohms and $R_L = 50{,}000$ ohms, then 5.5 volts would be developed across each. However, if $R_O = 50{,}000$ ohms and $R_L = 500{,}000$ ohms, then there would be developed across $R_O$ a 1 volt drop and across $R_L$ a 10 volt drop. This voltage across $R_L$ and $R_O$ would be the rectified half of the induced carrier voltage and would vary as the modulation caused the carrier voltage to vary. Therefore, the voltage across $R_L$ could be fed to an audio frequency amplifier, as in Fig. 14, or to headphones, as in Fig. 13 (here the headphones take the place of $R_L$).

Before considering the other diode illustrations, it would be well to restate some facts concerning the *ground* connections shown in these and other circuits. Because detector circuits are especially sensitive to *body capacity* and induced fields, such as the fields from house wiring, it has been noticed that ungrounded circuits will pick up and reproduce hum and clicks and interference not contained in the received signal. By connecting some portion to ground (usually the chassis of the receiver is at ground *potential*) such a circuit will be rendered less sensitive to these unwanted noises. This fact is true and is practiced throughout the communications field.

Because of the interconnection between circuits, for instance between the detector and audio amplifiers in Fig. 14, it is more convenient to use ground than to run another wire, since by so doing all circuits involved are close to ground potential and are not so sensitive to disturbing factors.

Inasmuch as the source of the voltage supplied to the diode is from the resonant circuit comprising LC, it would make no difference at what point we placed the ground connection. *However,* other circuits which might be connected to the diode circuit could dictate the point at which ground would be connected. Use is often made of this fact as will become evident from your study of Figs. 16, 17 and 18. These circuits have been isolated and *lifted* out of complete receiver diagrams in order that you may see some of the most used diode circuits.

If it were desired to have the varying output of a diode (output indicated as across $R_L$) so polarized that the positive lead would vary in relation to ground, then the circuits shown in Figs. 15 and 18 could be used. If, as when *automatic volume control* voltages are desired, it were advantageous to have the negative output vary with respect to ground, then circuits 16 and 17 could be used. In this latter case, the varying negative voltage would be applied to some RF stage or stages as C— bias and arranged so that the output of the diode would control the volume of the receiver. You will learn more about AVC in a future lesson.

For Fig. 16, an electron current flows up through $R_L$ as before with a consequent voltage drop across $R_L$ just as for Fig. 15. It may

seem difficult to understand how the plate may be identified as negative, but this potential is considered with respect *to the other end of the resistor and not with the cathode;* however, it will be noted that the plate *is* positive relative to the cathode. It may be recognized that the sum of $E_L$, the voltage across the load and Ep, the voltage across the rectifier are in series and add. The sum of Ep and $E_L$ comprise the total signal voltage supplied by the tuned circuit LC.

For example, if the tuned circuit supplies a peak of 11 volts across $R_L$ and $R_O$ which have values of 500,000 ohms and 50,000 ohms respectively, there will be a 1 volt drop across the tube and a 10 volt drop across $R_L$. The plate will be 1 volt positive with respect to the cathode and 10 volts negative with respect to the top of the LC circuit. It would be possible to obtain the output across $R_O$ with a 1 volt varying potential or to take the output from across $R_L$ where a 10 volt varying output is available. Consider that $R_L$ and $R_O$ have these values for all four circuits and study the polarities of the ends of $R_L$ and the diode elements. In this way, the circuits will be easy to understand.

Next, compare the circuit shown in Fig. 19 with that of Fig. 15. Here the source (the tuned circuit LC), the load $R_L$ and the rectifier D are still in series, but the point of the ground connection has been moved from the coil at X to the point between the rectifier and load. Although the ground could have been connected at any of the three points between the tuned circuit and load, the rectifier and load, or the rectifier and tuned circuit, only two of these possibilities were shown in Figs. 15 and 17.

The operation of the circuit of Fig. 17 is essentially like that of Fig. 15 except that the potential drop across $R_L$ in Fig. 17 is now negative with respect to ground instead of positive as in Fig. 15. This is simply due to moving the ground connection to the other side of $R_L$.

Because only half of each cycle of the wave (half cycle) is made use of in this type of circuit, it is called a *half wave rectifier.* You will recognize this as a principle which you studied in another lesson. Here again some power is lost due to the wasting of one-half of each cycle, as has been mentioned before.

It is obvious that the diode plate current is supplied by the signal.

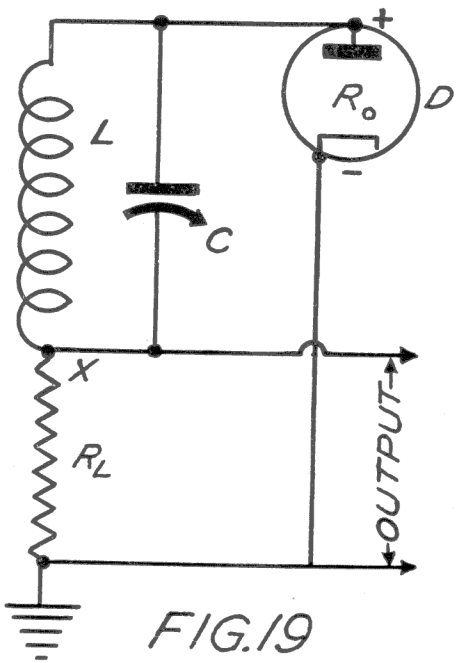



FIG. 19

The signal voltage rarely exceeds 25 volts. Moreover, the load $R_L$ is always made very large so that a major portion of the total voltage drop will be across it instead of across the tube—the latter being lost entirely. The diode current is, consequently, quite small. For this reason, the diode plates may be made very small in size, in fact, this function (diode detection) does not even warrant the use of a separate tube but may be put into other tube envelopes. Thus one tube may be made to perform several functions as, for instance, the 6H6 which is a duo diode (two diodes) or the 6Q7 a duo diode triode and the 6B7 which is a duo diode pentode. These combination tubes provide a saving in material and wiring besides saving space.

In modern receivers, it is sometimes desired to supply the AVC or AFC (automatic frequency control) or the electronic tuning indicator from a diode while supplying the AF amplifier with another diode; this is the reason for having duo diodes. All of these last mentioned improvements are completely covered in your future lessons.

Many designers have used triodes as diode detectors. You should remember that in many cases *triodes are used as diodes* with plate and cathode connected and grounded and with the grid acting as the diode plate. The plate then acts as an electron deflector or guide, increasing the rectifying efficiency of the detector.

## HOW A CONDENSER AIDS IN DETECTION

In the form indicated in Fig. 9, the half wave rectified carrier is still not suitable for audio frequency amplification because it is still a group of high frequency impulses all acting in one direction. Thus, the diode circuits from Fig. 15 through Fig. 19 are not completed detector circuits. To help accumulate the rectified energy a small condenser $C_1$, as in Fig. 20, is connected across the load $R_L$. Now as the voltage builds up across $R_L$ due to the high frequency pulsations, it must charge this condenser as well as force current through $R_L$. For an instant, the condenser draws so much current that the voltage across $R_L$ is reduced. It may charge almost instantly because of the relative low resistance of the diode. By the time the condenser is fully charged the first alternation (see Fig. 10) reduces to zero. The condenser cannot discharge at the same rate (the rate at which the alternations reduce to zero) through $R_L$ and hence cannot follow the voltage to zero with the alternation. The time required for a condenser to discharge through a resistor, as you will recall, is equal to the product of RC where R is the resist-

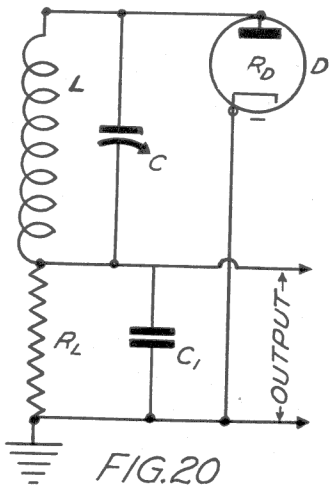


FIG. 20

ance in megohms and C is the capacity of the condenser in mfd. If the original wave has a frequency of 1000 KC (1,000,000 cycles), it will take one four-millionth of a second for the voltage of any alternation to reduce from maximum to zero (¼ cycle). A resistor $R_L$ of 500,000 ohms (as used in previous examples) and a capacity of .000000125 mfd., or .125 mmfd., would be necessary to allow a practically complete discharge in between each alternation. The condenser charges directly from the source through the rectifier tube almost instantaneously. In other words, it can easily follow the increasing voltage but cannot follow the reducing voltage. Now, if a condenser 1000 times as large is used, or approximately .0001 mfd. (100 mmfd,), it can discharge only a little even though the supply voltage goes to zero. The condenser in this case cannot discharge through the rectifier because its polarity keeps the plate of the tube negative with respect to the cathode during this time. The next alternation (still referring to Fig. 10), say the third one, has a higher peak value, but the voltage of it must build up until it equals that of the condenser before it can overcome the condenser charge and cause more current to flow through the rectifier. When this value has been attained, the condenser charges a little more until the next alternation or pulse is applied. It is evident from this that the charge of the condenser and the voltage across $R_L$ of Fig. 20 gradually increases. The condenser voltage follows the average energy within the rectified pulses which correspond to the original modulation wave which produced the signal voltage at the transmitter. The heavy line in Fig. 10 illustrates the average charge of the condenser. Notice its relation to the varying amplitude of the rectified carrier impulses. Beyond the maximum modulation peak, Mp of Fig. 10, each successive pulse 1, 2, 3, etc. of the rectified wave is less than the one preceding it to a point corresponding to Mo.

The value of condenser C in Fig. 20, used in this and similar circuits, is so chosen that it can only *discharge* with the audio or modulation pulses as from Mp to Mo in Fig. 10. The condenser cannot charge and discharge at a rate equal to the high frequency because of its reactance value. Therefore, the voltage across $R_L$ varies at a much lower rate than the high frequency voltage. Thus, condenser C absorbs the higher RF pulses and feeds them back to the circuit *at a rate corresponding to the frequency of the modulation.* Such a thing as this, however, can only happen when the product of C and R gives the correct time constant. Thus, filtering is a vital part of detection and is just as necessary as is rectification to complete the process.

Note that while the condenser cannot discharge in the short time interval between radio frequency impulses, it can easily discharge between two audio frequency peaks because of the lower frequency rate.

In this way it can be said that the condenser *filters out* the RF, leaving only the AF voltage across $R_L$. After the high frequency has

been removed, the remaining modulation voltage across $R_L$ would look like the curve shown in Fig. 12. It is simply a pulsating D.C.

Another way to consider the action of a condenser connected as in Fig. 20 is as follows: although the detector tube removes most of the RF, due to rectification, a small amount of RF remains even after rectification. You will remember this was also true of power supply circuits wherein a tube was used to rectify a high voltage 60 cycle current. Thus, after rectification, a certain amount of variation in voltage remains and this must be removed by means of filter condensers and chokes. In detector circuits, the principle is the same except the frequency is very much higher.

The remaining RF, after rectification, needs to be removed by means of filtering. A condenser connected across $R_L$, as in Fig. 20, will remove this remaining RF, provided it has the correct value. If a small value of condenser such as .00025 mfd. is used the reactance of it to low frequencies is great. Therefore, the audio voltage flows through $R_L$ because the resistance of it is much less than the reactance of C to low frequencies. From a high frequency viewpoint, the reactance of a .00025 mfd. condenser is very small. Therefore the high frequency flows through the condenser leaving only the audio or modulation frequencies to flow through RL. This, of course, is just what is wanted in order to feed the original modulation voltage to the audio amplifier of the receiver.

## COMPLETE DETECTOR STAGES

The modulation voltage cannot be fed directly to the grid of an audio amplifier as it would affect the normal bias of the amplifier tube and hence change the operating point on its characteristic curve. But the AC part of this voltage can be used by applying it through a condenser or a transformer which makes use only of the varying parts of the modulation voltage. The capacity or condenser coupling method is, by far, the most widely used.

A complete circuit of a diode detector and its coupling system to the audio amplifier is shown in Fig. 21. A 56 type tube, having its grid and plate electrodes connected together and used as a single plate, has often been used as a diode detector. Condenser C2 in Fig. 21 is for the purpose of coupling the signal voltage existing across $R_L$ to the grid of the following tube without disturbing the DC, just as C3, in the same figure, couples the first and second audio amplifiers thereby preventing the DC plate voltage from the plate of the second 56 tube from being passed onto the next grid.

The resistor V. C. (volume control) in Fig. 21 is a 500,000 ohms

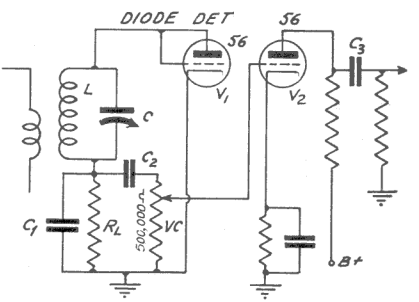


FIG. 21

potentiometer so that the slider may be moved up or down—thus allowing any portion or percentage of the maximum AF voltage available across VC to be fed to the grid of V2. *A control of volume is thus provided.*

The diode detector *does not amplify* a signal at all—in fact some of the signal energy is actually lost due to the natural resistance inherent in every circuit. Therefore, the output voltage across $R_L$ in a diode is always less than the voltage obtained from the RF amplifier. The signal voltage thus provided may be anywhere from the fraction of a millivolt on up to 25 or 30 volts. From the voltage induced in the antenna, ranging from a few microvolts to a quarter of a volt, it is raised to the former values, building up from a fraction of a microvolt to 25 or 30 volts by using RF amplifiers. Using three type 58 tubes or 78 tubes, for example, each having a gain of 80, a weak 1 microvolt signal may be built up to 80x80x80 or 512,000 times thereby providing a .512 volt input for the detector. A detector output of .5 volt could be further amplified by one audio triode approximately 12 times and a pentode approximately 20 times thereby delivering $.5 \times 12 \times 20$ or 120 AF signal volts to the speaker.

With 10 microvolts at the antenna, the RF gain could be reduced 51,200 times or only 1/10th of the detector output could be used by adjusting V.C. of Fig. 21, and still the same loudness of volume would be obtained as with the 1 microvolt input signal. You might ask why the detector should not be placed directly following the antenna coil so that the signals could be detected immediately and then use a high gain audio amplifier. This can be done, but this has *tuning disadvantages.* While the diode detector must have a fairly high signal input voltage, it will cover a large volume range of signals—giving better quality of output than will several other types of detectors.

## COMBINATION DIODE TUBES

The first of these combination tubes was the 55 which is a 2.5 volt filament duo-diode triode, combining a double diode and an audio amplifier triode. The 85 for the 6.3 volt filament rating was introduced at about the same time, and a little later the 75 was introduced with an exceptionally high amplification factor (100) for its triode section. This is often referred to as a *high-mu* tube. This tube has a 6.3 volt filament.

The two diode plates were provided in each tube so that full wave rectification might be provided thereby making use of all of the carrier energy. The use of a 55 tube, both for full wave and half wave operation is shown in Figs. 22 and 23. The full wave type is shown in Fig. 22, while the half wave circuit is shown in Fig. 23 with the two diode plates connected together to form one plate element. Other types of combination tubes are available with various ratings.

The operation of the full wave detector rectifier is just like the operation of a full wave power rectifier which you have already studied. The frequency, of course, is much higher—ranging anywhere from 130 KC to 500 KC in super-

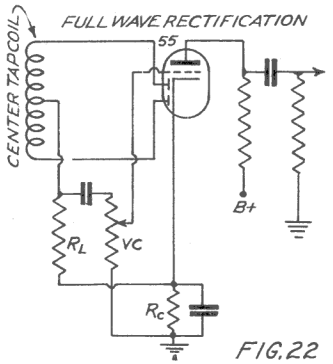



FIG. 22

heterodynes and up to 3000 KC and higher in multi-band receivers. Certain problems arise in connection with these high frequencies, but the process of rectification is the same for any frequency. Fig. 23 is just like the circuits which you have been studying except that the diode and triode are enclosed in a single tube envelope. In addition, a method must be provided for biasing the triode grid. Note in Fig. 23 that the load $R_L$ is returned diectly to the cathode while a resistor Rc connects the cathode with ground so that the triode is properly biased—the voltage drop across Rc providing the bias voltage.

In the circuits of today's radio receivers, you will see a good many variations of these basic circuits,

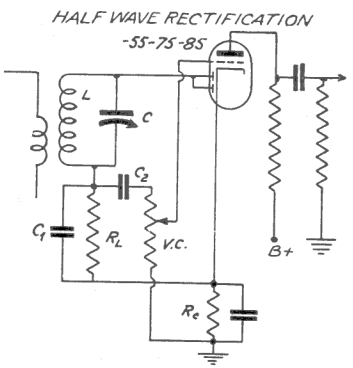



FIG. 23

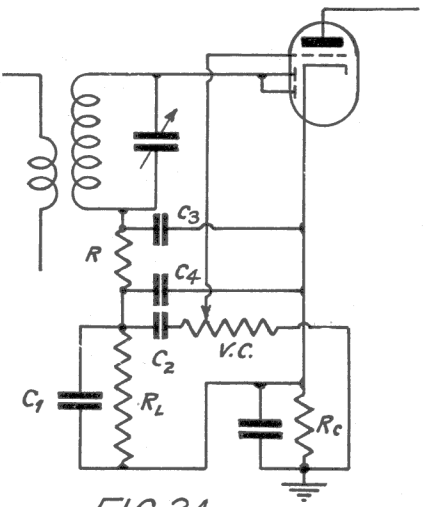



FIG. 24

the principles of which are explained in the following paragraphs. There will be, in almost every case, additional leads from these circuits for *automatic volume control* (AVC), but they are omitted from the circuits at this time. The subject of A.V.C. will be studied in detail later in other lessons.

In Fig. 24, a resistance capacity filter is shown consisting of resistance R and condensers C3 and C4.

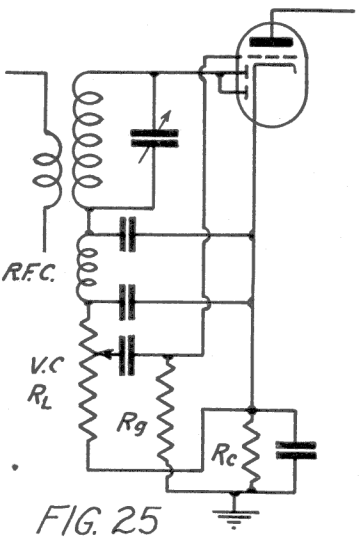



FIG. 25

R in this circuit, must be somewhat smaller than $R_L$ so that too much signal will not be lost across it. It ranges in value from 25,000 to 100,000 ohms—while condensers C3 and C4 are rarely greater in value than 250 mmfd.

In some cases a radio frequency filter is used having a choke coil RFC, and filter condensers in conjunction with the volume control (here it acts as $R_L$) as in Fig. 25. The D. C. drop across the choke coil is negligible making the circuit more efficient although more costly in design and construction.

When it is necessary to limit the voltage supplied to the grid, a circuit similar to Fig. 26 would be used. Here a fixed resistor R is in series with VC; thus the voltage is divided across the two and the volume control is limited to that portion of the available voltage developed across its own resistance. This system affords a means of compensating or controlling certain audio frequencies which the AF amplifier and speaker might not reproduce faithfully. This compensation or frequency selection is accomplished by adjusting the values of R, VC and C so that

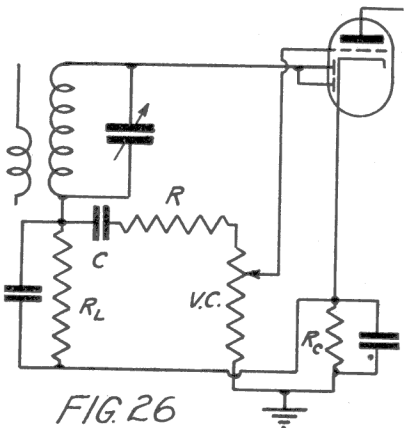


FIG. 26

the timing of the charge and discharge rate of C would be limited, thereby governing the maximum (or minimum) frequency which would pass to the grid. In this case, R may be from 10,000 to 100,000 ohms with VC rated at between .5 and 1 megohm. The coupling condenser C would be .01 mfd. or larger. You will learn more about tone compensation in later lessons.

A radio frequency transformer is not always used to couple to the diodes for, in some cases, capacity coupling is employed. An example of this type of coupling (condenser C) is shown in Fig. 27. In other respects its manner of operation is similar to the other methods described.

To the normal circuit may be added a tone compensator (Tc) as in Fig. 28. This consists of a resistor and condenser tapped into the volume control. As the volume is reduced, the high AF frequencies are suppressed (attenuated) more than the lower AF frequencies so that balanced reproduction will result. When volume is reduced with the ordinary circuit, the low frequencies already having little energy, drop almost out leaving only the high frequencies. This tone compensator avoids such trouble by reducing the *highs* more than the *lows* thus the illusion of even volume changes. This circuit also has a grid filter consisting of $R_1$, $R_2$ and $C_4$, the grid being biased from the voltage divider (the drop across R3) instead of using an individual cathode resistor.

It is frequently advantageous to prevent the diode detector cir-

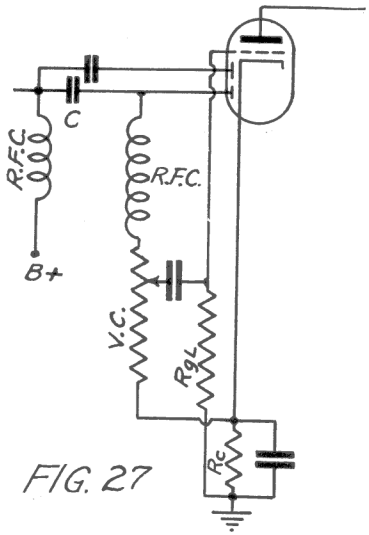



FIG. 27

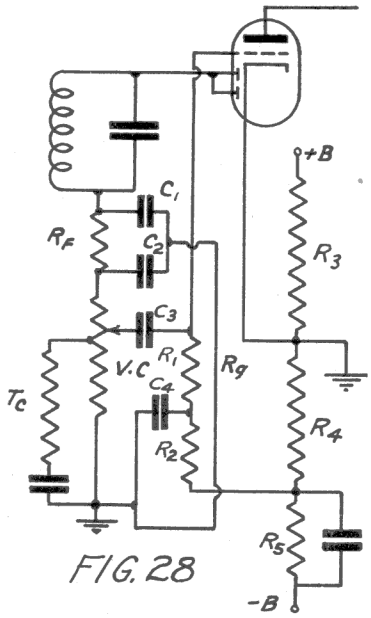



FIG. 28

cuit from operating until a definite signal level has been reached. This is done in Fig. 29 by *biasing the diode plates slightly negative* so that an equal or larger *positive signal alternation will be necessary* to start rectification and detection. This is accomplished in this circuit in the following manner. Due to the flow of plate current in the triode section of this combination tube, there will be reproduced across $R_1$ and $R_2$ a potential caused by the IR drop. If, for example, $R_1$ and $R_2$ were equal in resistance, and if there were a total drop of 6 volts across both of them, then by connecting the return of the diode circuit to the connection between $R_1$ and $R_2$, a difference in potential of 3 volts between the diode plates and the cathode would exist; consequently the diode plates would be more negative than the cathode. A signal applied to the diode plates, then, would have to have a potential greater than 3 volts before the positive half cycle of the signal would make the diode plates positive relative to the cathode. As you have learned before, the diode rectifier will function only when the diode plates are positive in respect to the cathode. To start detection, a signal must produce a minimum of 3 volts between the diodes and the cathode to bring

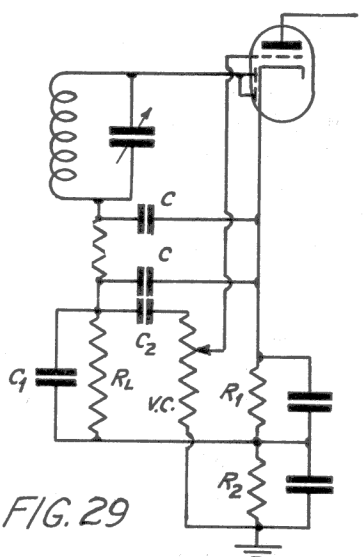



FIG. 29

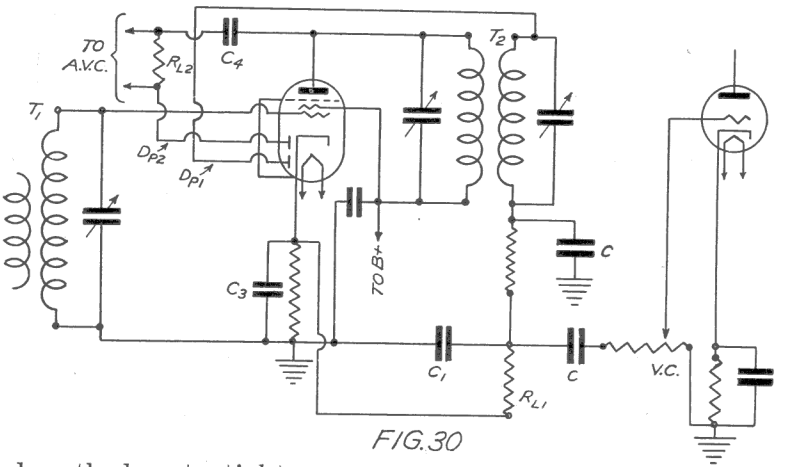



FIG. 30

the diode-cathode potential to zero. Any signal less than 3 volts will not be reproduced. The sum of resistance $R_1$ and $R_2$ compose Rc or the bias value for the triode control grid of the tube which, as you know, is an audio amplifier. Because this circuit *delays* reception until a certain signal level is reached, it is called a *delay detector circuit*. It has further significance than this in connection with the operation of automatic volume control circuits which will be described when this subject is explained.

You have seen the advantages of pentode tubes, both for RF and audio power amplifiers. It might easily be assumed that other combinations of tubes with the diode have been developed. Its combination with the voltage amplifying *pentode* of the RF type has been realized in the 2B7 for a 2.5 volt filament and the 6B7 for the 6.3 volt filament rating. One of its most common uses is shown in the circuit of Fig. 30. Because of this combination tube (called a duo diode pentode), it is possible to make a smaller receiver by combining several functions in one tube. In this circuit, the RF transformer $T_1$ supplies the control grid with a signal which is amplified by the pentode section of the tube in exactly the same manner as any pentode RF amplifier. This amplified signal is fed to the tuned output transformer $T_2$ which supplies, in turn, diode plate $D_{P1}$. The other diode plate $D_{P2}$ is supplied though its load resistor $R_{L2}$ directly from the pentode plate by condenser $C_4$. Diode plate $D_{P1}$ operates just as the other diode plates you have studied and delivers the rectified signal to the RF filter consisting of the two condensers C and to the load resistor $R_{L1}$. The grid of the first AF amplifier tube receives its signal from the voltage developed across $R_{L1}$ which is fed to VC by condenser C.

The voltage developed across $R_{L2}$, due to the flow of current through $D_{P2}$, is, in this case, the source of control voltage for the automatic volume control network and is simply indicated in this figure.

## POWER DETECTORS

You should now have a good understanding of the diode type of

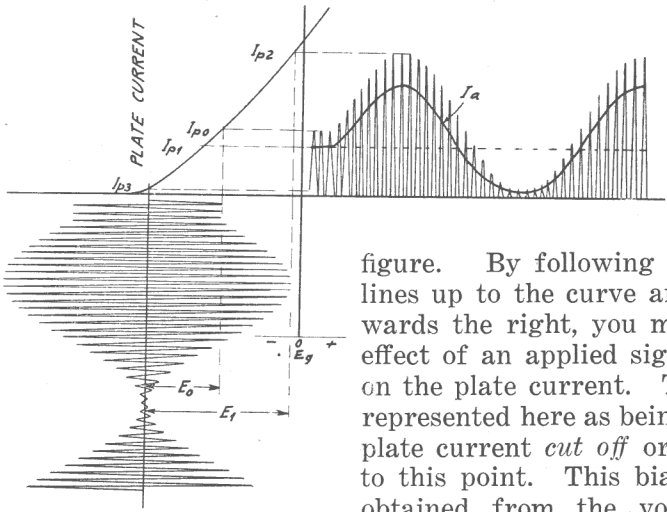



FIG. 31

detector. Thus you are now ready to devote your attention to other types of detector circuits. A common type of rectification can be attained through the use of certain amplifier tube characteristics which you have already studied.

You will remember that when a signal is applied to a triode, tetrode or pentode that, due to its operating point on the Eg-Ip curve, it would increase the plate current somewhat more on the positive alternation than it would decrease it on a corresponding negative alternation. Furthermore, you learned that if a tube is biased to the plate current cut-off point, the negative alternation will have no effect on the plate current as it is already zero, but the positive alternation will be amplified. A typical Eg-Ip characteristic curve of a tube having a reasonably straight section from zero grid voltage to plate current cut-off is shown in Fig. 31. In this curve, the varying or modulated carrier is shown at the lower left of the figure. By following the dashed lines up to the curve and then towards the right, you may see the effect of an applied signal voltage on the plate current. The tube is represented here as being biased to plate current *cut off* or very near to this point. This bias could be obtained from the voltage drop across a cathode resistor from a battery inserted in the grid return lead or from the voltage divider of the receiver's power unit. The average unmodulated carrier grid voltage Eo of Fig. 31 will cause a *peak plate current* of $I_{PO}$ with an average D.C. plate current $I_{P1}$. As the modulation voltage increases to $E_1$ (maximum), the peak plate current takes on a new value. The average plate current will be equal to the heavy curve Ia of Fig. 31. This is obtained by accumulating the pulses (filtering) as explained for diode detectors. It may be readily seen from the curves of Fig. 31 that rectification has been acquired though the signal has been transferred to the plate circuit from the grid circuit in the process. This is called *trans-rectification.*

As may be seen from Fig. 32, the circuit of this type of detector looks like an amplifier, except for the *plate circuit filter* and the fact that it has a tuned radio frequency output. The output load must be suitable for voltage amplification

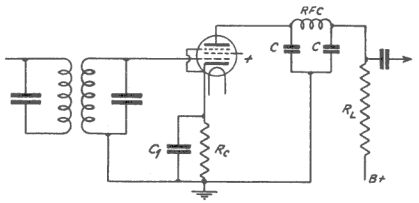


FIG. 32

of the audio frequencies to be expected in the modulated carrier input. The filter made up of RFC and two condensers C effectively smooths out any RF variations which may get into the plate circuit. Otherwise, the plate current will consist of a number of pulses as shown by the diagram of the original plate current in Fig. 31. If this type of current is made to flow through the primary of an iron core A. F. transformer, it will form its own filter but not an effective one. *The plate filter is a part of the detector system just as the necessary filter is part of an A.C. power supply system.*

Resistor Rc of Fig. 32 must have a high value often up to 50,000 ohms so that the grid bias will be great enough to almost cause plate current *cut-off*. You can see that actual plate current cut-off could not be obtained using this type bias, as current flow is required through Rc to produce the bias voltage drop. It may be observed also that while the action of the grid causes radio or high frequency pulses in the plate current, the plate filter (because of its reactance or impedence) reduces these to average values of audio frequency. Consider C1 by-passing Rc in Fig. 32 must be considerably larger for this purpose than for RF amplification. Its value may range from .5 mfd. to 10 mfd. which has the tendency to force a steady plate current, resulting in a steady negative bias voltage. The filter condensers in the plate circuit should not exceed .001 mfd. in value as larger values of C would filter out the audio frequencies as well as the high frequencies. The highest audio frequencies will be lost most easily. The values of C for detector plate circuit filters usually range between .0001 and .00025 mfd.

Any ordinary triode (not of the power amplifying type) may be used in this type of detector system. Such detector circuits as Fig. 32 are often called *power detectors*. They are also called *plate circuit* detectors. Tube types such as the 30, 27, 37 ,56 and a few others were widely used in earlier receivers. Likewise tetrodes of the detector-amplifier type such as the 22, 24, 24A, 36 and the ordinary pentodes such as the 57, 77 and the metal tubes types such as the 6J7 with improved characteristics are used in this way. Tetrodes and pentodes are most suitable for resistance coupling to the audio amplifier, while triodes may be transformer coupled if desired. This is true because tetrodes and pentodes are high impedance tubes —that is, they provide great changes in voltage for small changes in current. Triodes, on the other hand, are generally of lower impedance providing larger current changes which are necessary for effective transformer operation. The bias voltage values and, hence, the bias resistance values, are usually not accurately calculated but are determined by ex-

periment. Depending upon the nature of the receiver—its gain, selectivity, output desired, detector load, etc.—various values are used for Rc (as in Fig. 32 by various manufacturers).

## GRID CIRCUIT DETECTION

The next type of detection to which your attention is now called is the *grid circuit detector* or the *grid leak-condenser detector*. In its simplest form, it is shown in Fig. 33. As before, the tuned circuit LC acts as the signal source, having obtained energy from the RF amplifiers preceding it. Its modulated wave form is similar to that of Fig. 3.

Carefully note in Fig. 33 that the resistance R directly connects the grid to the cathode. This means that no signal being fed to the grid it will have no bias and will be at the same potential as the cathode. Now, neglecting the resistor for the moment, it will be seen that the grid will receive positive and negative charges from the tuned circuit through condenser C1. The capacity formed between the grid and the cathode elements of the tube is in series with the grid condenser C1, and the grid-cathode resistance and reactance, being much higher than the reactance of C1, the condenser receives by far the greater voltage distributed between the two.

Suppose that the grid is made 1 volt positive by one RF alternation from the LC circuit. For a moment, the grid will act as an anode or plate and a small grid current will flow—thus charging condenser C1 to a potential of 1 volt. Electrons flow, of course, from the cathode to the grid. This will give

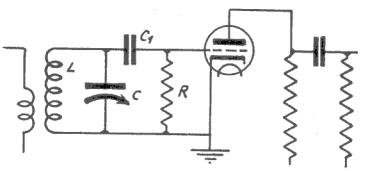



FIG. 33

the condenser a charge of 1 volt with a polarity such that the grid will be connected to the negative side of it and the positive side will be connected to the coil L.

Reaching this charge of 1 volt almost instantly, the charging cannot continue because the condenser C1 now has a voltage equal to the supply across LC and the cathode-grid current ceases, the grid now being at cathode potential. For an instant, the coil L may be regarded as a 1 volt cell, and the grid-cathode space may be regarded as a resistance when the condenser C1 has reached a charge equal to the voltage of the imaginary battery. See Fig. 34. When this condition is reached, there is no further charging current through the cathode-grid circuit indicated as G-K in Fig. 34. It must be carefully noted under this condition that no voltage exists across G-K as it is at ground potential at every point.

Now, without breaking the circuit, suppose that the battery voltage suddenly reduces to zero, *which is actually what happens with the coil of Fig. 33.* It will be noted that the condenser voltage is now entirely impressed across the grid and cathode as there is now no battery (or coil) voltage to counteract it. But this time, due to the charge remaining in the condenser C1, the grid will be 1 volt negative with respect to the cathode as will be seen in Fig. 35.

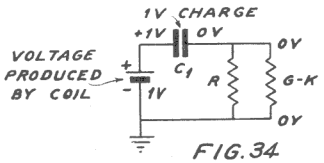


FIG. 34

Since the voltage across the condenser remains the same, when the voltage of one of its terminals is reduced, the other will reduce accordingly. You will have seen how one positive pulse or alternation in this circuit will give the grid a negative charge. You know, too, that while the grid is negative, no cathode-grid current can flow. The coil voltage not only drops from 1 volt positive to zero, but in addition goes to 1 volt negative. Thus, the total grid voltage when the signal impresses 1 volt negative on the grid is 2 volts negative with respect to the cathode. It is the sum of the voltage across the condenser and that across the coil (or battery, if you consider it reversed as in Fig. 36).

On the second positive alternation, the coil voltage will merely subtract from that of the condenser C1 and will have to equal the condenser voltage to bring the grid to zero voltage. However, if a start is made with a carrier voltage of .5 volt and it is built up to 1 volt in accordance with sine wave modulation, as in Fig. 37, the grid will first become .5 volt negative on the first positive alternation and 1 volt negative on the first negative peak of the carrier. Its average negative value will remain at minus .5 volt until the modulation of M starts in Fig. 37. At the modulation peak Mp, the grid will reach a total negative charge of 2 volts with an average of 1 volt. Here is an important point—the carrier energy must decrease from a maximum peak of 1 volt at Mo as in Fig. 37, and there must be some way for the grid to lose the negative charge which it has accumulated. Otherwise it will

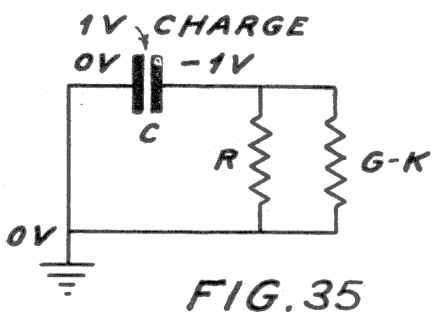


FIG. 35

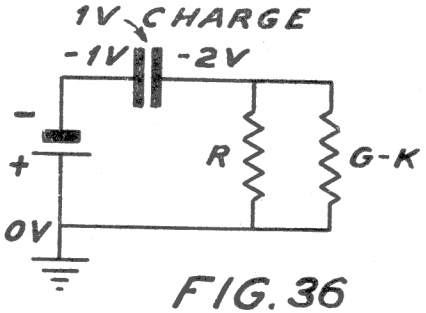


FIG. 36

remain negative and the reduced signal will have little or no effect on it. This is accomplished through the grid load (or leak) resistance R, so called because it allows the charge of C1 of Fig. 33, and, hence, the grid charge to leak off to ground or to a point of zero potential. As you have noted before, this discharge of a condenser through a resistor requires a definite time determined by the values of C1 and R. Values of .0001 to .00025 mfd. for C1 with 1 or 2 megohms for R are most generally used.

At Mo of Figure 37, the grid condenser is completely discharged, the grid is at zero voltage and the signal is, of course, zero. Figure 38 shows the actual voltage wave form resulting on the grid with the RF supplied to it. During the detecting process, the grid will acquire its own bias which will be practically equal to the peak carrier voltage acting on it. This will become evident if, for the moment, you overlook the plate and merely regard the tube as being a diode in which the grid is acting as a diode plate. The tendency of condenser C1 to hold these RF charged pulses will be to filter out the RF or high frequency from the grid except for successive small increases and decreases of carrier peaks. The grid, therefore, is ultimately supplied with an AF voltage.

In the diode circuits a desirable portion of the audio signal flowing through the diode load resistance was fed to the grid of the next tube. In Fig. 33, essentially the same thing takes place except the grid-leak serves as the load. However, instead of tapping off a portion of it and introducing it into another tube or another section in the same tube for audio amplification it is simply amplified directly by the detector tube. Note in this system of detection the audio frequency occurs or comes into use during the process of grid rectification. The plate circuit acts as the audio amplifying part of the system.

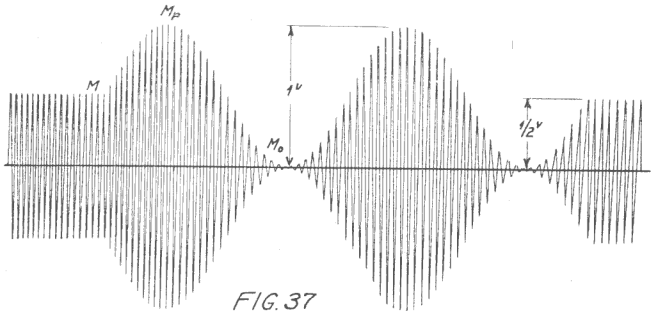



FIG. 37

It will be observed that the operating point of the tube—that is, its average grid voltage or bias point on its grid voltage-plate current characteristic—is **determined entirely by the average carrier energy fed to it.** It may be different with each carrier received and changes during the reception of one signal with the variation of average carrier voltage. The charges which accumulate on the grid are amplified a number of times, depending on the voltage amplifying power of the tube and its load (which, incidentally, must remain low because of the nature of the circuit).

Very often the grid-leak resistor is placed directly across the grid condenser instead of from the grid to cathode as shown in Fig. 39. Since it (the grid-leak or resistor) carries the audio frequency discharge current of the grid condenser, it makes no difference which connection is used. The **coil** offers negligible reactance or resistance to audio frequencies so a good electrical circuit is provided through it to the cathode.

As for other detector systems, triodes, tetrodes and pentodes alike may be used for grid circuit detection. Common to all grid circuit detectors are low plate voltage (22.5 volts to 135 at the supply source), low signal input voltages (below 1 volt) and, consequently, high sensitivity that is capable of operating satisfactorily on low signals.

Because of the curvature of the lower end of the Eg-Ip characteristic curve of a detector tube, the audio output signal voltage is not proportional to the input RF voltage. If only a small signal is applied, not much advantage can be taken of the relatively greater **increase in plate current** than the decrease for equal positive and negative relative values of grid voltage. However, when the signal becomes larger, considerably more curvature may be taken in the grid voltage plate current range—thus increasing the proportion of detection.

The shape of the Eg-Ip curve is such that the audio signal voltage is approximately proportional to the square of the RF grid signal voltage. Rather than an advantage, as this would seem to be from the viewpoint of sensitivity, this type of detection produces considerable distortion in the rectifying process. Distortion will be produced in any detector where the output voltage is not exactly proportional to the input voltage. Detection in any system which is acquired by curvature or resistance variation with input causes distortion and should be avoided. The grid leak-condenser, the crystal detector and the small signal diode detector are **curvature operated** or square law detectors.

In contrast to these detector systems are the power grid and diode types called linear because the line representing the plot or graph of the voltage-current characteristics is approximately a straight line.

The grid leak-condenser detector requires little or not filter in the plate circuit as practically all of the RF energy is filtered out in the grid circuit. In regenerative detectors, some of the RF must remain in the plate circuit for the purpose of regeneration as will now be explained.

## REGENERATION

When the first triode detectors were in use, experimenters were constantly in search of a method of increasing their sensitivity. This would accomplish two

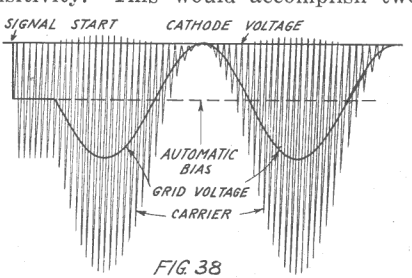



FIG. 38

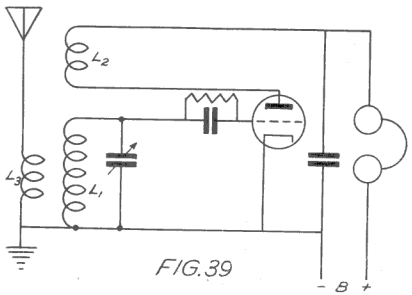


FIG. 39

things. First it would allow the reception of signals which could not be heard otherwise, and secondly, such an improvement would reproduce signals louder than before. One of these methods is termed **regeneration.**

This regeneration was accomplished by taking the portion of amplified RF which remained in the plate circuit after rectification and sending it back through the tube again. How this is accomplished may be seen by referring to Fig. 39. By inserting a coil ($L_2$) in series with the plate and load of a detector (this plate coil is called a **tickler**) and by placing it close to the detector input coil, $L_1$, (magnetically coupled) the plate coil will induce, into the input coil, that amplified portion of RF remaining in the plate circuit. By using less turns in the plate coil, a transformer action will take place between the tickler and input coils thus stepping up the voltage of this RF giving it more control over the grid circuit. Although its **feedback** voltage may be slightly out of **phase** with the original RF, it will not seriously impare the **quality** of the audible signal.

In the development of this circuit, another phenomenon made itself noticeable. By adjusting the position of the tickler coil in relation to the input coil, it was found that it was possible to drive the detector tube into violent oscillation. This would cause squeals and howls to be heard in the phones or speaker and could be started even though no signals were

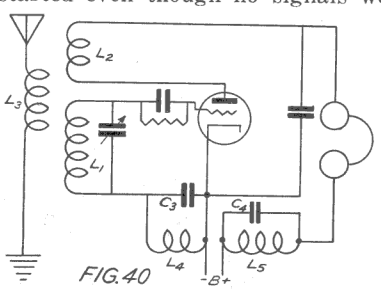


FIG. 40

being received. Some surge of static or electron emission in the detector tube or the surge caused by the motion of the tickler coil would be sufficient to start a series of voltage surges in the input coil which, in turn, would cause a larger surge in the tickler coil. This would drive the grid still further and create a larger surge in the plate or tickler coil, and this feedback would continue to multiply until the tube's maximum plate current prevented further building up of energy. Here another discovery was made. As soon as the detector went into oscillation, speech became unintelligible —however, just before reaching the point of oscillation, any signal being received would become enormously louder. If the operator could keep the tickler just below the point of oscillation, signals could be heard loudly, which, without regeneration, were just barely audible. Thus, **controlled regeneration** became one of the most popular methods of receiving weak signals.

Some objections were found to regeneration. Among them was the **instablity** of such circuits. The least shock or impulse of interference was sufficient to start the receiver oscillating; then, too, and this was quite important, a receiver operated in or near an oscillating condition **re-radiated** energy from its antenna, much as a small unmodulated transmitter, and this caused interference with neighboring receivers. Regeneration added another control and the trend in **broadcast** receivers is toward the simplification of control. Methods were developed to correct these and other faults, and regenerative detectors are today being used in modern communications.

Because it increased the efficiency of a receiver, controlled regeneration is an advantage and can be used to increase the overall **gain** of a receiver. It is not used on most broadcast receivers because of the additional controls necessary for its operation.

## SUPER REGENERATION

It will be recalled that a regenerative detector was most efficient just as it approached the point of oscillation. It had also been noticed that if one deliberately created a voltage surge to start oscillation, there was a noticeable lag before the tube started to oscillate. It was found that if during this lag period, another surge was created opposing this tendency to oscillate and if these two impulses were kept up continuously and automatically, the best regenerative op-

erating point could be maintained. Further, if these two impulses could be created in the detector circuit at a rate per second which would be **above** audibility, no extra sound, like the squeals and howls of the ordinary regenerative detector would be heard. The circuit shown in Fig. 40 was developed. Notice that the tickler of the regenerative detector $L_2$ is coupled to the input coil $L_1$ just as it is in Fig. 39. Two more resonant circuits are provided in Fig. 40 consisting of $L_4$, $C_3$ and $L_5C_4$; the constants for these two coils are so chosen that they produce oscillations at frequencies of around 18,000 cycles per second. This is called the **quenching frequency** and serves to start and stop oscillation in the detector circuit as outlined previously. Because this frequency is above the limits of audibility, only a slight hiss will be heard when no signal is being received. This system may be used with either grid or plate detectors and may also be used in some special applications of diode detection. The quenching frequency can be, and often is, supplied from an extra tube in the receiver. It is more economical to use the detector tube itself, and by properly adjusting the components of the circuit, this may be done without impairing its efficiency as a detector; on the contrary, this will multiply the sensitivity greatly.

**These questions are desigend to test your knowledge of this lesson. Read them over first to see if you can answer them. If you feel confident that you can, then write out your answers, numbering them to correspond to the questions. If you are not confident that you can answer the questions, re-study the lesson one or more times before writing out your answers. Be sure to answer every question, for if you fail to answer a question, it will reduce your grade on this lesson. When all questions have been answered, mail them to us for grading.**

# QUESTIONS

**No. 1. What are the two distinct parts or actions of detection?**

**No. 2. What does the rectifier part of a detector accomplish?**

**No. 3. How may a triode tube be arranged to act as a diode detector?**

**No. 4. How can detection be delayed until a definite signal level is reached?**

**No. 5. What is a SQUARE LAW detector?**

**No. 6. What is the amplification gain of a diode detector tube?**

**No. 7. Figure 21 shows a two tube diode detector with a stage of triode amplification. What circuit in this lesson, using one tube, is its equivalent?**

**No. 8. How is the grid bias voltage for a grid leak-condenser detector developed?**

**No. 9. What distinguishes a triode power detector from a triode amplifier?**

**No. 10. For what important reason are diode and power detectors preferred instead of the grid leak-condenser type in present day receivers?**